New system hardware issues remaining at the time that development was terminated included the probable need for a small increase in the byte interleaver size to equalize the burst noise performance with respect to the GA system, although this was not thoroughly investigated. It would have been necessary to re-arrange the order of the elements of the field sync segment to implement airplane flutter detection in the manner employed in the GA system prototype receiver. There was a need to re-program certain PROMs/PLDs to implement 10-level slicers in the equalizer and phase tracker, and to implement a circuit for detecting whether the new system NTSC rejection filter should be in or out.

Advantages of the new system, other than improved ATV service, are described below. These include improved acquisition time and multipath-plus-co-channel performance under some reception conditions.

In Section 2. we discuss the history of co-channel interference mitigation approaches including those used for the GA system, the ATVA systems, and a Hitachi proposal. In Section 3 we describe the new system. The practical implementation of the new system is discussed in Section 4. In Section 5 we compare the performance of the new system and the GA system, and in Section 6 we draw some conclusions.

2. BACKGROUND

One of the main system issues faced in designing a U.S. ATV terrestrial transmission scheme is the presence of co-channel NTSC interference during the transition to ATV-only broadcasting. The co-channel NTSC signal impairs the performance of the digital ATV receivers, and the co-channel ATV signal impairs the performance of the analog NTSC receivers. In the latter case, the interference is noise-like since the digital signal has a flat spectrum. The ATV-into-NTSC interference will not be as harmful as the NTSC-into-ATV interference since ATV will be broadcast at much lower power levels than NTSC. The digital ATV signal is very severely affected by the presence of NTSC, which has two main carriers: the picture and sound carriers, as well as a lower power color sub-carrier.

2.1 Grand Alliance (GA) System

The GA system deals with NTSC-into-ATV interference by placing a comb filter at the receiver before the equalizer and trellis decoder. The comb filter places notches at the approximate positions of the NTSC picture and sound carriers. However, it also places notches at other points in the spectrum, where they are not necessary. The deleterious effect of these notches is countered in the trellis decoding by considering the trellis code at the transmitter followed by the comb filter at the receiver as a composite trellis code and decoding accordingly at the receiver. This approach works well in the presence of co-channel interference only, but has a 3 dB loss in additive white Gaussian noise (AWGN) performance due to the noise enhancement of the comb filter. To avoid this 3 dB loss whenever possible, the comb filter and its associated trellis decoder is switched in only when the receiver detects the presence of co-channel interference. According to [4], this detection is done by comparing mean-squared errors at the input and output of the comb filter using the field sync. Considerably more complicated metrics may be required to reliably implement the switching of the comb filter, as will be made clear in Section 2.1. The comb filter also increases the number of possible levels of the 8-VSB signal to 15. Therefore, the equalizer must process a 15-level input signal when the comb is engaged.

The GA system trellis encoder shown in Fig. 1 implements the standard rate 1/2 4-state Ungerboeck code. The precoded bit is not trellis coded, while the second input bit is coded with the Ungerboeck code, for an overall rate 2/3 trellis code. The simple 4-state Ungerboeck code was chosen to keep the complexity of the trellis decoder within acceptable limits, in the case when the comb is switched in. This is because use of the comb filter in the receiver leads to an increased number of states in the trellis decoder. Decoder hardware complexity is exponentially related to the number of states. A second technique, described below, is used to minimize trellis decoder complexity.

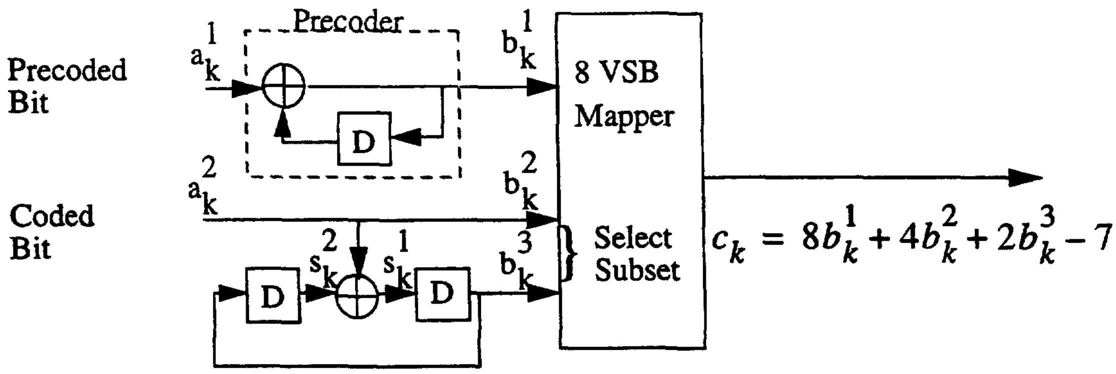


Figure 1. GA Trellis Encoder. Note that, since D represents a delay of 12 symbols, this diagram describes an implementation using 12 parallel encoders.

From a conceptual point of view, a 12 x 12 symbol interleaver is placed before the trellis coder in the transmitter. If we call any arbitrary symbol '0' and the next symbol '1', etc., the 12 x 12 symbol interleaving is accomplished by encoding symbols {0,12,24,36,...} as one group, symbols {1,13,25,...} as a second group and so on for a total of 12 groups. The trellis coder outputs are then appropriately multiplexed to form the transmitted data stream. Note that with the delay D equal to 12 symbols in Fig. 1, the GA trellis encoder implements this parallel trellis encoder arrangement very simply.

At the receiver, the trellis decoder operates in one of two modes. When the comb filter is not switched in, it is the standard 4-state trellis decoder for the above-described rate 2/3 trellis code. When the comb filter is switched in, a trellis decoder optimized for the concatenated rate 2/3 trellis code and comb filter is used. In the receiver, a conceptual 12 x 12 symbol de-interleaving, followed by a comb filter with transfer function $1\text{-}D^{-12}$ (where D represents a time delay of one symbol interval) in effect produces 12 separate trellis coded streams each subject to a $1\text{-}D_1^{-1}$ transfer function (where D_1 is equal to 12D). Since the uncoded bit in the trellis encoder was precoded, it can be shown that the optimal trellis decoder for this rate 2/3 trellis code followed by the $1\text{-}D_1^{-1}$ channel has 8-states. The 12 x 12 interleaving, trellis coding, and comb filter chain can be viewed as 12 separate trellis encoded data streams each subject to the same $1\text{-}D_1^{-1}$ channel and each decoded by an optimal 8-state decoder. Thus trellis decoder complexity, even for the case when the comb filter is switched in, has been limited to 8 states by the use of this interleaving technique and the precoding of one bit.

2.1.1 GA System Comb Filter Performance

The GA system was field tested [3] on Channel 6 in Charlotte, NC. An independent analysis of the field test data, presented in [5], concluded that at low Desired (ATV) signal to Undesired (NTSC) signal (D/U) ratios, the comb filter "sometimes acted in a 'random' fashion", and that "its effectiveness was not very convincing". This unreliability of the comb filter switch can cause VSB signal recovery failures (bit error rate below the "threshold" needed for reception) at low carrier-to-noise (C/N) ratios.

The unreliability of comb filter switching can cause further problems with regard to time-varying phenomena. A burst of impulse noise or changing multipath can cause the system to temporarily decide to switch from a comb-inactive mode to a comb-active mode, or vice versa. Every time such a switch is made, various components such as the comb filter switching circuit, equalizer, trellis decoder, etc., must readapt, which may result in a burst of errors, all of which must then be dealt with by the A/V layer of the MPEG video decoder.

Time-varying signal fades (which are known to be at times as much as 20 dB) can cause greater problems, even if it is assumed that the comb filter switch operates reliably. Fig. 2 shows the performance of the GA system for the two scenarios when the comb filter is always active, and when the comb filter is always inactive. These two graphs identify three regions as shown - Region A where the comb is not active, Region B where the comb may or may not be active and Region C where the comb is always active. Given a specific received power level of the desired ATV signal and the interfering NTSC signal, it is possible to define an "operating point" corresponding to a specific carrier-to-noise ratio (CNR), and D/U Ratio, which for reliable transmission must be in one of the three Regions A, B, or C. Due to a signal fade associated with the ATV signal and/or the interfering NTSC signal the operating point can move between these regions. Such a "region transition" will cause the system to be temporarily unstable, because the comb filter change detector, equalizer, trellis decoder, and other components must adapt to the changed situation. Effectively, the comb operation will be unreliable in the shaded area as shown in Fig. 2.

To summarize, not only are there reliability issues associated with the comb filter switching scheme as implemented, in general, attempting to do filter switching by detecting co-channel interference at the ATV receiver can also lead to poor performance under changing signal conditions. In contrast, the new system provides a co-channel rejection approach that functions reliably because it does not depend on making difficult filter in/out switching decisions at the receiver. It is independent of signal fades unless the signal fade causes the system threshold to be met.

2.2 ATVA Proposal

The ATVA proposed a QAM scheme [2] which was evaluated against 8-VSB for selection as the GA terrestrial transmission scheme. While there were many differences between the ATVA scheme and the GA transmission scheme, we discuss only the features relevant to combatting co-channel interference.

The primary method used by ATVA-QAM system is to use a very long (256 tap) T/2-spaced equalizer to combat co-channel interference. Considering the interference as additive non-white noise with a frequency-selective nature, it can be expected that the equalizer should be able to compensate for an averaged NTSC spectrum. However, this approach has problems. The NTSC spectrum,

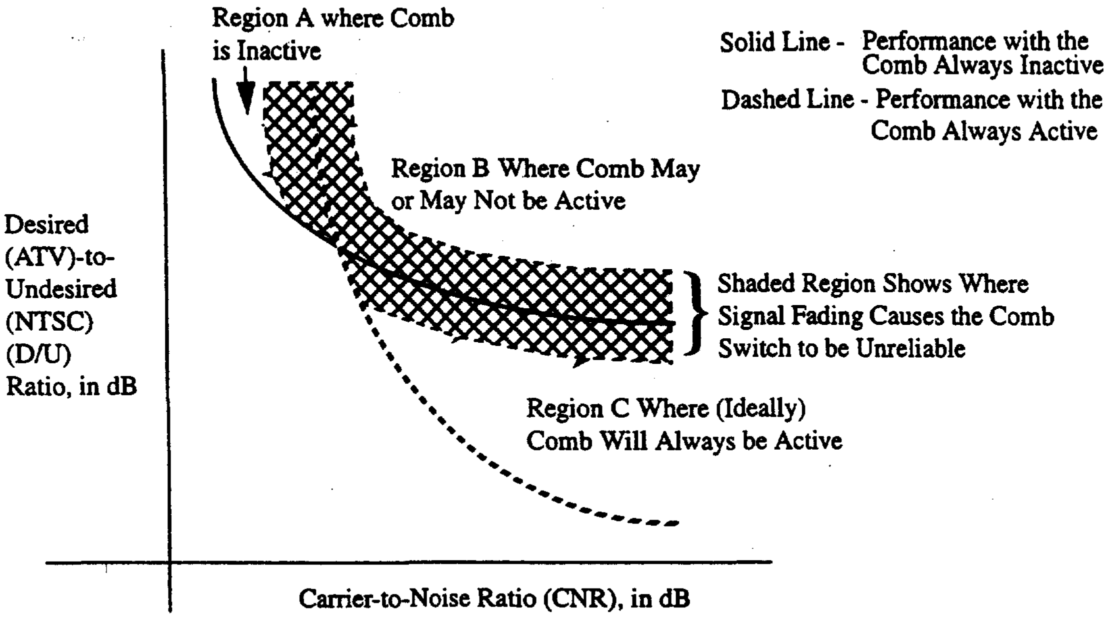


Figure 2. Performance of the GA system showing the Unreliability of Comb Filter, Whenever Changes in Signal Power or the Interfering Co-Channel Power Causes the Transitions Between the Regions as Shown.

as explained earlier, has most of its energy concentrated near a few carriers. Hence, to create an extremely selective notch, a very long equalizer is required. But as the size of the equalizer is increased, excess mean-square error (MSE) at the output of the equalizer plays an increasing role. Furthermore, with a large number of taps and due to the non-stationary nature of the NTSC interference, it becomes increasingly difficult to train the equalizer optimally. It is then clear that some NTSC interference rejection aid is required for mitigation of co-channel NTSC interference.

2.3 Hitachi Proposal

Hitachi proposed a receiver-based co-channel interference rejection strategy [9]. The basic idea is to employ several infinite-impulse-response (IIR) filters to precisely notch out the NTSC picture, sound, and color sub-carriers. These notches can be made adaptive to take into account the case when co-channel interference is absent. Also these notches have very small bandwidths, hence creating very little additional inter-symbol interference.

However, we found that co-channel NTSC interference, even though mainly confined to frequencies close to the NTSC picture, sound (and to a much lesser extent) color carriers, has a bandwidth in the neighborhood of these carriers in excess of what can be sufficiently removed using sharp IIR filters. This is especially true in the case of the NTSC sound-carrier, where FM modulation spreads the carrier to quite some extent. By our simulations, it was determined that the IIR notch proposal did not provide as good a performance as the GA comb filter when only co-channel interference was present, although it did offer better performance over some part of the expected co-channel-plus-noise operating range. In addition, the same concerns about reliable rejection filter switching noted for the GA system would apply to the Hitachi proposal.

3. NEW SYSTEM DESCRIPTION

3.1 Overview

The proposed system has four key components that are different from the GA system: (1) a different trellis code, (2) a precoder in the transmitter and corresponding NTSC rejection filter in the receiver (3) a different symbol interleaver and (4) a different byte interleaver. These components are shown in Fig. 3 and Fig. 4. The trellis code is a 2-dimensional 6-VSB code that delivers a greater simulated coding gain (0.2 dB at threshold as shown in Fig. 14) than the 1-dimensional 8-VSB code used in the GA system. The filter that is used in the transmitter as a precoder and at the receiver as a rejection filter is designed in such a way that it minimizes the NTSC interference while constraining the noise enhancement to a specified small value of 0.3 dB. In this respect, it is different from the comb filter which filters out the NTSC at the expense of a 3 dB increase in noise level. Due to the small noise enhancement of the proposed filter, it does not have to be switched out when NTSC interference is absent, as is the case with the comb filter. The symbol interleaver is a short interleaver that is designed to "whiten" the noise at the input to the trellis decoder. This takes the place of the 12-symbol interleaving used in the GA system. The size of the byte interleaver is increased slightly as compared to the GA system in order to deal with the impulse spreading due to the rejection filter in the receiver. Each of these components will be described in greater detail below. In addition to the above changes, minor modifications are needed to the training sequence in order to perform equalization properly at the receiver. These modifications were not implemented in the hardware that was tested, but are described in our new system description document submitted to ACATS [14].

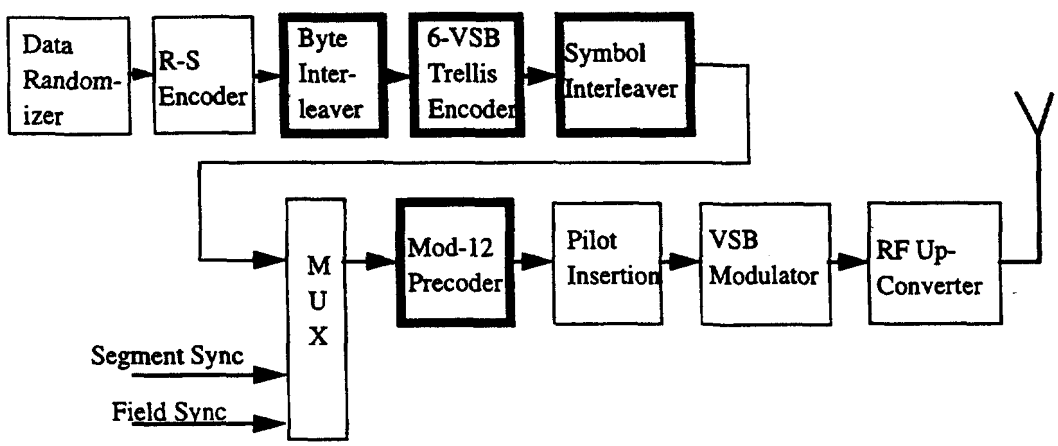


Figure 3. Block Diagram of the Transmitter of the New System - Modifications to the GA System Transmitter are Shown in Bold.

Fig. 4 shows the receiver block diagram of the new system, which can be compared with Fig. 9 of [1] for the GA system. The rejection filter is placed before the equalizer and has the same coefficients as those used in the transmitter precoder. A symbol de-interleaver is inserted between the phase tracker and trellis decoder and the new byte interleaver is inserted before the Reed-Solomon decoder. The filter can be bypassed at the receiver under the control of a block which processes a section of the field sync segment to determine whether the filter should be bypassed. The advantage of switching the filter out is an improvement in system threshold of about 0.3 dB over the GA system. Broadcasters who foresee no co-channel problem can disable the filters today, while all broadcasters can gain this system threshold advantage when NTSC ceases operation.

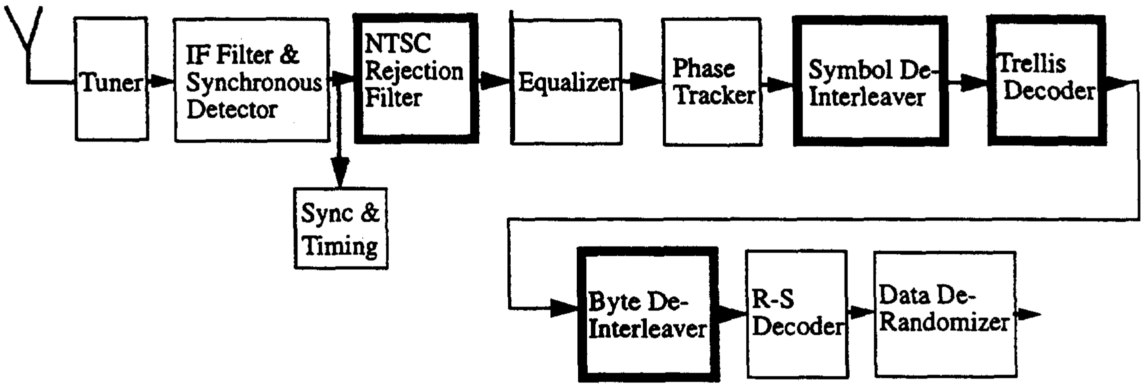


Figure 4. Block Diagram of the Receiver of the New System - Modifications to the GA System Receiver are Shown in Bold.

3.2 NTSC Rejection Filter

All of the proposed NTSC cancellation schemes involve some kind of filtering in the receiver. The Hitachi solution uses short IIR filters to insert notches at the NTSC carrier frequencies. The ATVA solution uses the equalizer to do adaptive filtering of the NTSC interference, and the GA system uses the comb filter. Since all of these approaches are in the receiver only, they must necessarily filter the desired digital signal along with the NTSC interference. Further, in the presence of both white noise and NTSC, this filtering actually enhances and 'colors' the noise while reducing the NTSC signal. Both of these effects (filtering the digital signal and noise enhancement) lead to worsened error performance in the presence of white noise plus NTSC interference. This is why the comb filter in the GA system has to be disabled when only white noise is present.

3.2.1 NTSC Rejection Filter Design

With the new system this problem is solved by first designing a rejection filter to minimize the interference, while keeping the noise enhancement down to 0.3 dB, and then using the same coefficients in a precoder at the transmitter. The design of the filter is done as follows. Let i_k be samples of the NTSC interference sampled at the symbol rate (10.76 MHz for the GA system). Let the filter taps be $\begin{bmatrix} 1 & g_1 & g_2 & \cdots & g_N \end{bmatrix}$ where the first tap is constrained to be 1 and the number of taps is N. Constraining the first tap to be 1 makes the filter suitable for use as a precoder in the transmitter. Essentially the filter is a one-step predictor of the NTSC signal. The NTSC variance at the output of the filter is given by:

$$J = \begin{bmatrix} 1 & \underline{g}^T \end{bmatrix} R_I \begin{bmatrix} 1 \\ \underline{g} \end{bmatrix} \tag{1}$$

where $\underline{g} = \begin{bmatrix} g_1 & g_2 & \cdots & g_n \end{bmatrix}^T$ and R_I is the correlation matrix of the NTSC interference. The variance of the noise at the filter output is proportional to $\underline{g}^T\underline{g}$. Hence, the criterion for determining the filter $\underline{g}$ can be stated as: minimize J with respect to $\underline{g}$ subject to the constraint $\underline{g}^T\underline{g} = k$ where k is some constant which specifies the allowable noise enhancement. For example, for a noise enhancement of 0.3 dB the value of k is 0.07. The above minimization can be carried out in a straightforward manner using Lagrange multipliers. Let us rewrite R_I in partitioned form as follows:

$$R_I = \begin{bmatrix} a & \underline{b}^T \\ \underline{b} & C \end{bmatrix} \tag{2}$$

where $\underline{b}$ is a N X 1 vector and C is a N X N matrix. Then the minimization criterion becomes: minimize $a + 2\underline{g}^T\underline{b} + \underline{g}^T C\underline{g} + \lambda(\underline{g}^T\underline{g} - k)$ with respect to both $\underline{g}$ and λ. This reduces to solving the following equations for $\underline{g}$ and λ:

$$\underline{g} = (C + \lambda I)^{-1}\underline{b} \tag{3}$$

$$\underline{g}^T\underline{g} = k \tag{4}$$

These equations cannot be solved in closed form for $\underline{g}$ but can be fairly easily solved for a given value of k by computing $f(\lambda) = \underline{b}^T(C + \lambda I)^{-2}\underline{b}$ as a function of λ and picking that value of λ for which $f(\lambda) = k$. Once λ is known, $\underline{g}$ can be calculated from Equation (3).

The above method requires a knowledge of the correlation matrix of the interference. This was obtained by sampling an NTSC color-bars signal at the symbol rate and then estimating the correlation from the time samples. These correlation values were then used in the above algorithm to design a filter with 51 taps (i.e., N = 51) that had a noise enhancement of 0.3 dB while attenuating the NTSC color-bars signal by 13.36 dB. Although the filter was designed with the correlation values of the color-bars signal, it was found that the attenuation with other NTSC signals (e.g. "Text-over-Tulips") was also about the same. This is expected, since the correlation basically extracts spectral information from the signal and the spectrum of the NTSC signal does not change appreciably (most of the energy remains near the carriers) with the actual content of the signal. Fig. 5 shows the spectrum of the NTSC color-bars signal and the frequency response of the rejection filter designed with the above algorithm.

3.2.2 Modulo-12 Precoder

Tomlinson-Harashima precoding [10], [11] is a well known means of precoding a signal against a known channel and is used primarily for improved performance in a multipath environment. In the co-channel case, one can view the rejection filter at the receiver as intentionally-introduced multipath distortion on the signal. If the signal was precoded against this multipath at the transmitter,

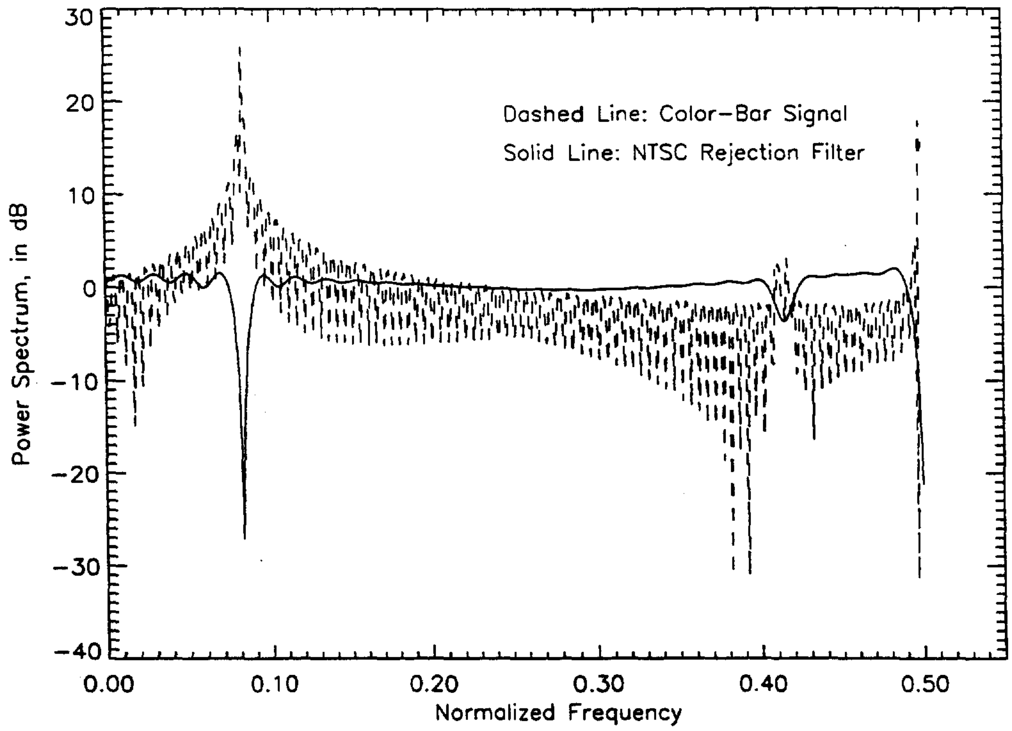


Figure 5. Power Spectrum of the NTSC color-bars signal (averaged over multiple frames) and the NTSC Rejection Filter.

the signal part of the rejection filter output would be unaffected except for a modulo transformation. This is illustrated in Fig. 6.

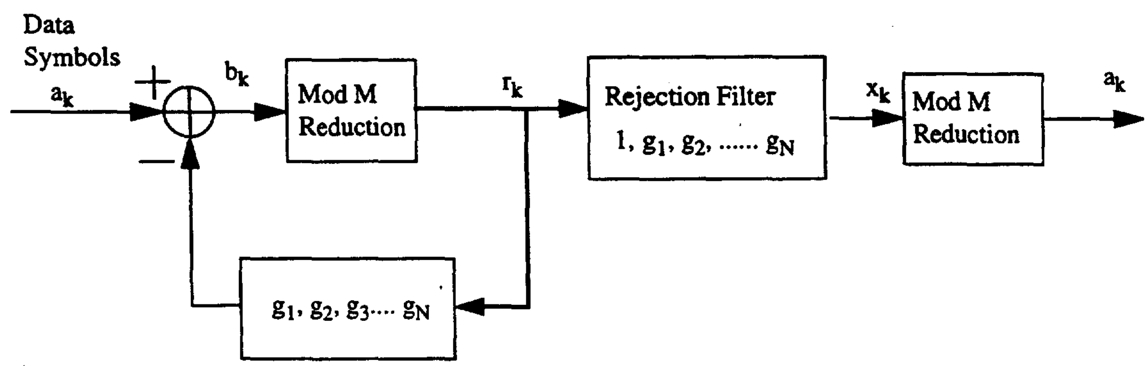


Figure 6. Transmitter-Receiver Rejection Filter Arrangement Using Tomlinson-Harashima Precoding.

Let a_k be the transmitted symbols. Then the output of the modulo-precoder is given by

$$b_k = a_k - \sum_{i=1}^{N} g_i r_{k-i}$$

$$r_k = (b_k) \mod \mathrm{M} \tag{5}$$

where the mod M operation is defined as follows: If b_k is greater than M/2, M is subtracted an integral number of times until the result is less than M/2. If b_k is less than -M/2, M is added an integral number of times until the result is greater than -M/2. This nonlinearity ensures that the output of the precoder is always bounded between -M/2 and M/2 and hence is always stable. M is chosen large enough to accommodate the constellation of a_k. For a 6-VSB constellation, with symbol points ± 1, ± 3, ± 5, M is chosen to be 12. When r_k goes through the rejection filter at the receiver, which has the same coefficients as the transmitter precoder, the filter output is given by:

$$x_k = r_k + \sum_{i=1}^{N} g_i r_{k-i}$$

$$= a_k \mod \mathrm{M} \tag{6}$$

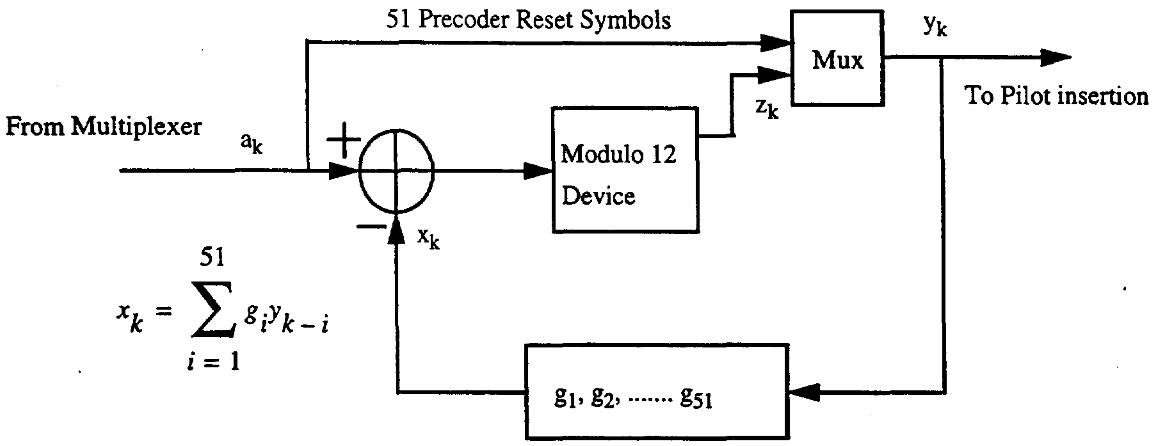
Hence, a_k can be recovered from x_k by a mod M operation. Due to the mod M nonlinearity, x_k will have more levels than a_k, the exact number depending upon the filter being used. With the filter design that was implemented in hardware, it was found by simulations and actual experiments that the number of levels at the filter output never exceeded 10 when the 6-VSB trellis code was used.

At the transmitter, the filter obtained by the procedure described in Section 3.2.1 is used as a precoder as shown in Fig. 7. The output of the trellis encoder is multiplexed with all the synchronization signals and then sent through the precoder. When the 51 "precoder reset" symbols (described in Section 3.2.3) arrive at the beginning of the field sync, they are sent to the output through the multiplexer as shown in Fig. 7. The feedback part of the precoder is thus reset at the beginning of every field sync by these 51 known symbols. The coefficients of the feedback part of the precoder are the same as the coefficients used in the rejection filter in the receiver. Due to the modulo-12 operation, distinct levels are not seen any more at the output of the precoder. Instead, the transmitted signal is uniformly distributed over [-6,+6].

3.2.3 Field Sync Segment Modifications

Two changes are proposed to the GA field sync specification: the insertion of "precoder reset" symbols and "filter-mode detect" symbols. These are described below and illustrated in Fig. 8.

Due to the precoding in the transmitter, which is essentially an IIR filter, the output of the receiver filter during the field sync will vary from one field to the next. This could be a problem for some blind equalization detection schemes that average successive field syncs. In order to ensure that the



If a_k is a Precoder Reset Symbol, then $y_k = a_k$; otherwise $y_k = z_k$

Figure 7. Precoding with the Precoder Reset Symbols.

← 832 Symbols →

Sync	Preco-der Reset	PN511	PN 63	PN 63	PN 63	Filter Mode	VSB Mode	Reserved
4 Sym.	51 Symbols	511 Symbols	63 Sym.	63 Sym	63 Sym.	8 Sym.	24 Sym	45 Symbols

Figure 8. Modified Field Sync Symbols.

output of the receiver filter is deterministic during the field sync duration, it is proposed to insert 51 precoder reset symbols at the beginning of the field sync. These symbols are the same as the last 51 symbols of the 511 symbol long training sequence and are inserted as shown in Fig. 7. In the receiver, the data during these symbol intervals are not used for equalizer training. The equalizer starts training after the Precoder Reset symbols have been received.

To allow future receivers to infer whether the precoder was used at the transmitter or not, 8 symbols are used to designate such a mode. These symbols are proposed to be as follows:"00010001" would denote that the transmitted signal was not precoded while "11101110" would denote that the transmitted signal is precoded.

3.3 Trellis code

The GA transmission system is based on an inner one-dimensional (1-D) 4-state trellis-coded 8-VSB. A major inefficiency of any 1-D trellis-coded modulation (TCM) is that it adds one redundant bit per dimension of the signal constellation. As a result, the size of the 1-D constellation needs to be doubled, from 4-VSB to 8-VSB in this case where the number of bits input to the trellis encoder is two per signaling interval. Generally speaking, in designing a digital communication system, it is desirable to keep the size of the constellation as small as possible. The smaller the constellation is, the more robust the receiver is. This is especially true for those channel impairments other than Gaussian noise, such as various linear or nonlinear distortions from over-the-air transmission. The smaller constellation can also help to reduce the implementation loss.

3.3.1 Two-Dimensional Trellis Coded 6-VSB

A multidimensional TCM can be used to reduce the size of the constellation of a 1-D TCM. It also has the potential to offer a greater amount of coding gain. An N-dimensional TCM with $N > 1$ is constructed using an N-dimensional constellation that is formed with a number N of 1-D constellations in the time domain. An N-dimensional TCM adds only 1/N redundant bits per dimension. For example, a 2-D TCM adds only 0.5 redundant bits per dimension and a 6-VSB constellation is sufficient in the present case of two input bits per signaling interval.

Fig. 9 - Fig. 11 describe the details of a 2-D 8-state trellis-coded 6-VSB modulation that is proposed to replace the inner 1-D 4-state trellis-coded 8-VSB of the GA system. Both the 2-D and 1-D decoders have comparable complexities in the absence of an NTSC co-channel interference rejection filter. However, the complexity of the 2-D decoder remains about the same when it is used with the proposed NTSC rejection filter, while that of the 1-D decoder is at least doubled when it is used with the GA system comb filter.

Referring to Fig. 9, eight input bits, a_0, a_1, a_2, a_3, a_4, a_5, a_6 and a_7 are collected over four symbol intervals. Two of these, a_0 and a_1, sequentially enter an 8-state rate-1/2 convolutional encoder, with four output bits, Z_1, Z_2, Z_3 and Z_4 generated as shown in Fig. 10. Each of these bits is used to select a 1-D subset A or B as shown in Fig. 11. The remaining six bits, a_2, a_3, a_4, a_5, a_6 and a_7 enter a fractional bit encoder which outputs four 2-bit pairs X_mY_m, m=1,2,3 and 4 according to Table 1. Each pair X_mY_m is then used to select a symbol from the subset previously selected by Z_m. The mapping of the bits $X_mY_mZ_m$ to symbols of the 6-VSB constellation is shown in Fig. 11.

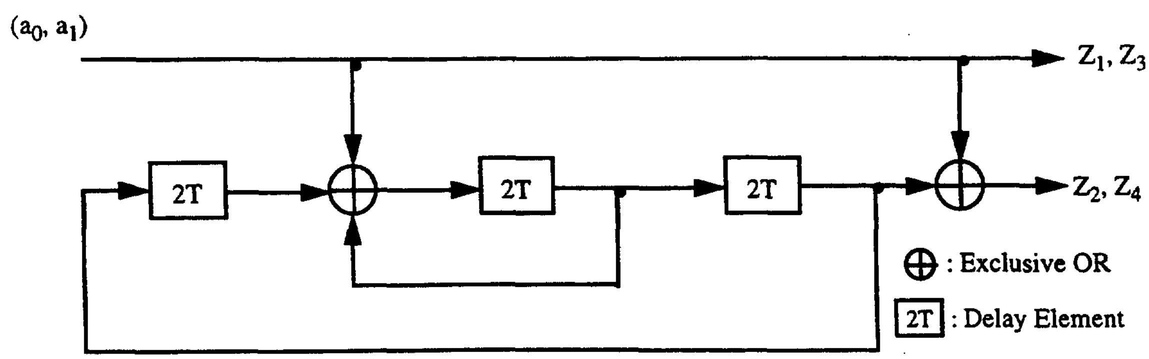


Figure 10. 8-State Rate-1/2 Convolutional Encoder.

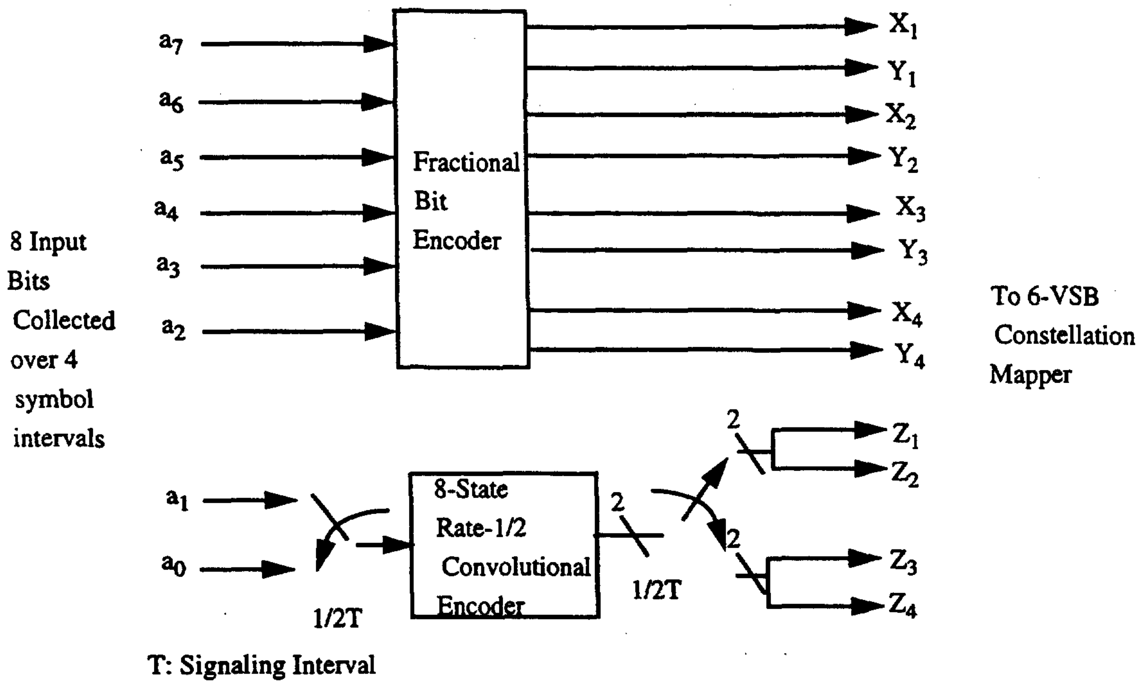


Figure 9. Two-Dimensional 8-State Trellis-Coded 6-VSB.

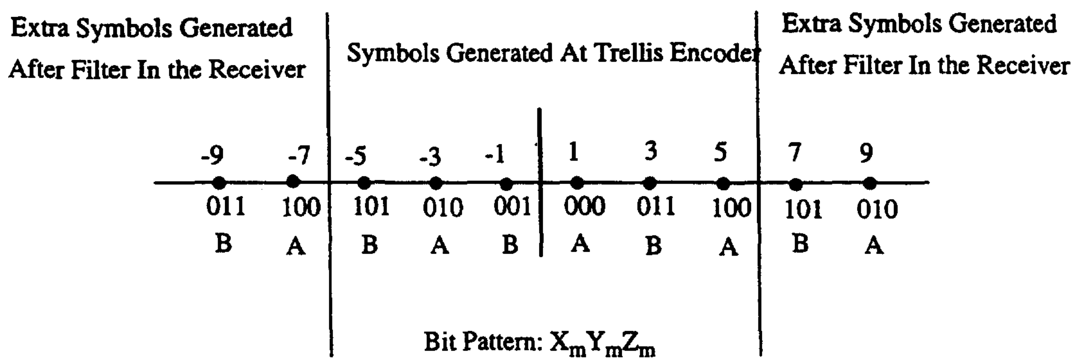


Figure 11. 6/10-VSB Constellation Mapper.

Interested readers may have noticed that the 2-D trellis code here is not of the conventional type. Although its convolutional encoder operates in the 2-D space, its constellation mapper operates in the 4-D space. There is a slight performance advantage from using a 4-D instead of a 2-D constellation mapper. Further, the four inner symbols of the 6-VSB constellation (-3, -1, 1, 3) have a higher probability of occurrence as compared to the two outer symbols (-5, 5). This can be used to perform maximum-a-posteriori (MAP) decoding at the trellis decoder in the receiver to get an additional gain. This is discussed further in Section 5.2.5.

Input Bit Pattern	X_1Y_1	X_2Y_2	X_3Y_3	X_4Y_4	Input Bit Pattern	X_1Y_1	X_2Y_2	X_3Y_3	X_4Y_4	Input Bit Pattern	X_1Y_1	X_2Y_2	X_3Y_3	X_4Y_4	Input Bit Pattern	X_1Y_1	X_2Y_2	X_3Y_3	X_4Y_4
0	0	0	0	0	16	2	0	0	0	32	2	1	0	0	48	2	0	2	0
1	0	0	0	1	17	2	0	0	1	33	2	1	0	1	49	2	0	2	1
2	0	0	1	0	18	2	0	1	0	34	2	1	1	0	50	2	0	0	2
3	0	0	1	1	19	2	0	1	1	35	2	1	1	1	51	2	0	1	2
4	0	1	0	0	20	0	2	0	0	36	1	2	0	0	52	0	2	2	0
5	0	1	0	1	21	0	2	0	1	37	1	2	0	1	53	0	2	2	1
6	0	1	1	0	22	0	2	1	0	38	1	2	1	0	54	0	2	0	2
7	0	1	1	1	23	0	2	1	1	39	1	2	1	1	55	0	2	1	2
8	1	0	0	0	24	0	0	2	0	40	0	0	2	1	56	2	1	0	2
9	1	0	0	1	25	0	1	2	0	41	0	1	2	1	57	2	1	2	0
10	1	0	1	0	26	1	0	2	0	42	1	0	2	1	58	1	2	0	2
11	1	0	1	1	27	1	1	2	0	43	1	1	2	1	59	1	2	2	0
12	1	1	0	0	28	0	0	0	2	44	0	0	1	2	60	2	2	0	1
13	1	1	0	1	29	0	1	0	2	45	0	1	1	2	61	2	2	1	0
14	1	1	1	0	30	1	0	0	2	46	1	0	1	2	62	0	1	2	2
15	1	1	1	1	31	1	1	0	2	47	1	1	1	2	63	1	0	2	2

TABLE 1. Fractional Bit Encoder Mapping. Note that Input Bit Pattern is a_7,a_6,a_5,a_4,a_3,a_2

The 8-state convolutional encoder of Fig. 10 is the same as that in Table B-2 of [12], except that the encoder is of the systematic type. If a slightly better performance is desired, one may use a convolutional encoder with a larger number of states from that table. Generally speaking, trellis codes that are constructed using the convolutional codes of [12] are not good by themselves. However, as described in [13], these trellis codes become good when they are used together with a relatively powerful outer code, such as the RS(208,188) used here.

3.3.2 Trellis Decoding

In the absence of the NTSC rejection filter and its associated mod-12 precoder as described in Fig. 3 and Fig. 4, the trellis decoder is a usual Viterbi decoder that is based on the 6-VSB constellation. However, in the presence of the filter and precoder, the receiver constellation is expanded from 6 to 10 symbols, with four extra symbols at coordinates -9, -7, 7, and 9 as shown in Fig. 11. The figure also shows how the 10 symbols are partitioned into two subsets A and B, and how each symbol is mapped back to the bit pattern $X_mY_mZ_m$. The trellis decoder then proceeds as usual as if a 10-VSB constellation were used by the encoder.

The simulated performance of the 2-D trellis code with and without the rejection filter and mod-12 precoder is shown in Fig. 14.

3.4 Interleavers

Suboptimal byte and symbol interleavers were used during the performance testing of the new system, because of time limitations. In this section we describe the higher-performance interleavers proposed in our new system description document submitted to ACATS [14].

3.4.1 Byte Interleaver

Although the R-S code is particularly powerful in protecting against burst errors, the data is interleaved for further protection. The goal of the interleaver is to spread the data bytes from the same R-S block over time so that a burst of noise must be very long to cause more than 10 data byte errors (overrun the R-S error protection). The insertion of the rejection filter in the receiver causes a burst to be spread over 52 symbols, although the filter tap values are not very large, and so the effective spreading is significantly less than 52 symbols. To compensate for the effect of the filter, we propose a deeper interleaver in the new system, as described below.

The interleaver employed in the new system is a 52 data segment (intersegment) convolutional byte interleaver. Interleaving is provided to a depth of about 1/6 of a data field (4 ms deep). The interleaver performance is improved with respect to the GA system by increasing the delay of the interleaver of Fig. 12 from 208 (52 x 4) to 312 (52 x 6). Only data bytes are interleaved. Field and segment sync are not included in the interleave process, since they are not added until later. Each of the 52 parallel data streams are delayed by D_i bytes, i=1,2,...52, where $D_i = 6*(i-1)$. This interleaver and RS code combination can tolerate error bursts of up to 730 bytes, which is about 271 μs.

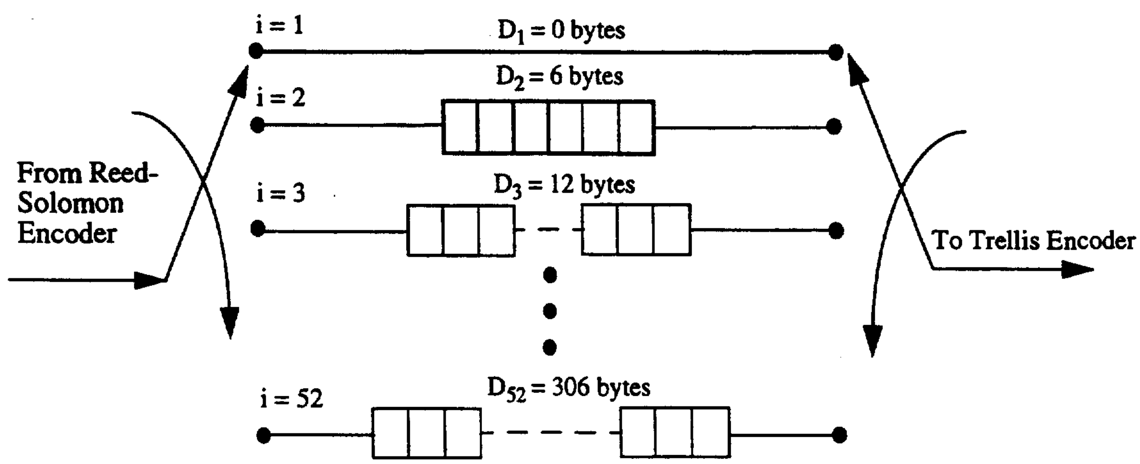


Figure 12. Convolutional Byte Interleaver for the New System.

The convolutional de-interleaver performs the exact inverse function of the transmitter convolutional interleaver. Its 1/6 data field depth, and intersegment "dispersion" properties allow noise bursts lasting about 271 μs to be handled as compared to 193 μs for the GA system. Again, each parallel data stream is delayed by Di bytes, i=1, 2,... 52 where Di = 6*(52-i). This deinterleaver requires 7956 bytes of memory to implement. Even strong NTSC co-channel signals, which can pass through the NTSC rejection filter and create short error bursts due to NTSC vertical edges, are reliably handled by the interleaving and R-S coding process.

3.4.2 Symbol Interleaver

The trellis encoder is followed by a symbol interleaver which randomizes the trellis coded symbols and is useful in combating co-channel NTSC interference. The symbol interleaver is implemented as a 24 symbol x 52 symbol block interleaver. Symbols are read in by rows and read out by columns. The number of rows is 24 and number of columns 52.

The symbol deinterleaver is the reverse of the interleaver used in the transmitter. Hence, it is a 52 symbol x 24 symbol block interleaver where the number of rows is 52 and number of columns 24. Data is again read in by rows and read out by columns.

3.5 Equalizer and Phase Tracker

Although many implementations are possible, the GA system equalizer and phase tracker described in [4] can be used (and perform essentially the same) in the new system if the 8-level slicer (15-level slicer when the comb filter is switched in) used in the GA system is replaced by a 10-level slicer for the new system. Since the noise and data both go through the receiver filter, they have the same correlations, and hence the operation of the equalizer is not affected. By slicing on 10-levels instead of 6, the equalizer does not try to compensate for the rejection filter. Hence, NTSC interference is handled primarily by the rejection filter while multipath equalization is handled by the equalizer.

3.5.1 Blind Equalization

The new system can be used with the GA blind equalization scheme, or other blind equalization schemes. The insertion of the Precoder Reset symbols at the beginning of each field sync will ensure that the output of the receiver filter during the training sequence is deterministic and hence successive training sequences can be averaged to determine the presence of airplane flutter. This rearrangement of the field sync symbols was not implemented in the hardware. Other detection scenarios which do not require this rearrangement are also possible, but were not implemented in hardware either.

4. NEW SYSTEM IMPLEMENTATION

There is a minor increase in complexity at the ATV transmitter to include the pre-coder for the new system (mainly, a 50 tap FIR filter), but this cost can be considered negligible in the context of the overall expense to implement the transmitter. In the following, we describe the complexity of the new system implementation at the ATV receiver.

4.1 Canonical-Sign-Digit Filter for Implementation of Rejection Filter

A canonical-sign-digit (CSD) implementation of the new system co-channel filter has shown that the filter can be implemented using 50 adders/subtracters. Hence, assuming an 8-bit A/D converter, the additional complexity of the new system is fifty 8-bit adders/subtracters, with fifty-one 8-bit registers.

4.2 Trellis Encoder and Decoder Implementation

It was not possible to implement a single trellis decoder in the hardware prototype of the new system because the fastest general purpose trellis decoder available in 1994 was a chip which could operate at a maximum decoding rate of 1 MHz. With this chip, the new system 2-D trellis code had to be implemented using eight parallel decoders. To ensure that each decoder operated on essentially different streams, an interleaving scheme was devised such that 156 consecutive symbols were sent to each successive decoder. An analogous encoding and interleaving strategy was used at the encoder. Hence, even though a single high-speed trellis decoder was not implemented, for the purposes of evaluating the performance of this code, this implementation was considered to be equivalent to the new system specification.

The complexity of the trellis decoder is described as follows. It is an eight-state decoder operating at one-fourth the symbol-rate. In contrast, the GA system must implement an eight-state decoder operating at symbol-rate. However, some additional complexity is associated with the fractional-bit decoder, which amounts to a 256 x 6 ROM. Still, the trellis decoder complexity of the new system is less than the trellis decoder of the GA system.

4.3 Equalizer

The equalizer for the new system is implemented as in the GA system, except for the following modifications. During training using the field sync, the first 51 symbols are ignored. Furthermore, the binary-level signal is now a four-level signal. But all these four levels are known precisely and can be stored in a ROM. Hence, an error signal can be generated by using the received symbol and the stored symbol, which can then be used to train the equalizer in a decision-directed fashion. A deterministic four-level signal also allows metrics to be generated to aid the blind-equalization algorithm as described earlier. The complexity of the equalizer for the new system is the same as the complexity of the GA system equalizer.

4.4 Interleavers

Convolutional interleaving will be used which reduces the difference between the byte interleavers for the new system and the GA system to $7956 - 5304 \cong 2.65$ kB. A small amount of additional memory is required for the new system symbol de-interleaver, which is 1248 bytes. Using a convolutional symbol interleaver, this memory can be reduced to 624 bytes. Hence the total additional memory required with the new system over the old system is 3.27 kB of RAM.

4.5 Rejection Filter Switching

The hardware to detect the filter mode is a simple serial correlator consisting of 1 adder and 1 register. In contrast, to determine whether the comb filter needs to be switched in or out may require very complex algorithms, especially if efforts are undertaken to minimize the unreliable switching due to signal fades, impulse noise, etc.

4.6 Cost Comparison

In general, the additional complexity required to implement the new system is minimal. A comparison between an ATV receiver without a comb filter (not considering possibly complicated comb filter switching mechanisms) and the new system showed that the new system cost 60 cents more for logic and memory in the first year (1996), decreasing to only 15 cents more in the year 2001.

5. PERFORMANCE COMPARISON OF THE NEW SYSTEM AND THE GA SYSTEM

The performance of the new system and the GA system is compared below in terms of test results, simulation results, and discussion of performance areas not tested or simulated.

5.1 Test Results

In January of 1995, representatives of the GA and ACATS performed testing at Zenith Electronics to measure the co-channel-plus-noise and noise-only performance of the new system and GA hardware. Additional tests for burst noise performance were performed at that time. Zenith also reported some results of their own private testing for frequency offset sensitivity, peak-to-average power ratio, and transmitted signal spectrum.

5.1.1 Co-Channel-Plus-Noise

NTSC-into-ATV co-channel-plus-noise results were obtained for 6 different interfering video sequences suggested by the GA Video Specialist Group. Fig. 13 shows the results for the "Text-over-Tulips" video, which was considered the most challenging test of NTSC-into-ATV co-channel performance available to the GA. The co-channel-only results for all 6 video sequences tested are given in Table 2. Fig. 13 illustrates that the major difference between the new system and the GA system is in the area of 15-20 dB desired (ATV)-to-undesired (NTSC) (D/U) ratio where the GA system comb switches in, causing the system CNR threshold to degrade by 3 dB. The new system co-channel-plus-noise performance was better than that of the GA system, over the majority of the co-channel plus noise range, for all 6 video sequences tested, and better in co-channel-only for 5 of the 6 video sequences. Performance with co-channel-only was found not very significant in the overall ATV service area results, as described in Section 5.2.2 below.

Interfering NTSC Video Sequence	GA System D/U Ratio (dB)	New System D/U Ratio (dB)
Text-over-Tulips	+1.45	+0.07
Mobile-and-Calendar	-1.80	-2.47
Flower Garden	-1.54	-2.54
Race-Car	-1.87	-0.96
Kiell Harbor	-0.76	-1.94
Popple	-1.64	-1.78

TABLE 2. Desired (ATV)-to-Undesired (NTSC) Signal Ratio (D/U ratio) for the GA System and the New System for Various Interfering NTSC Videos.

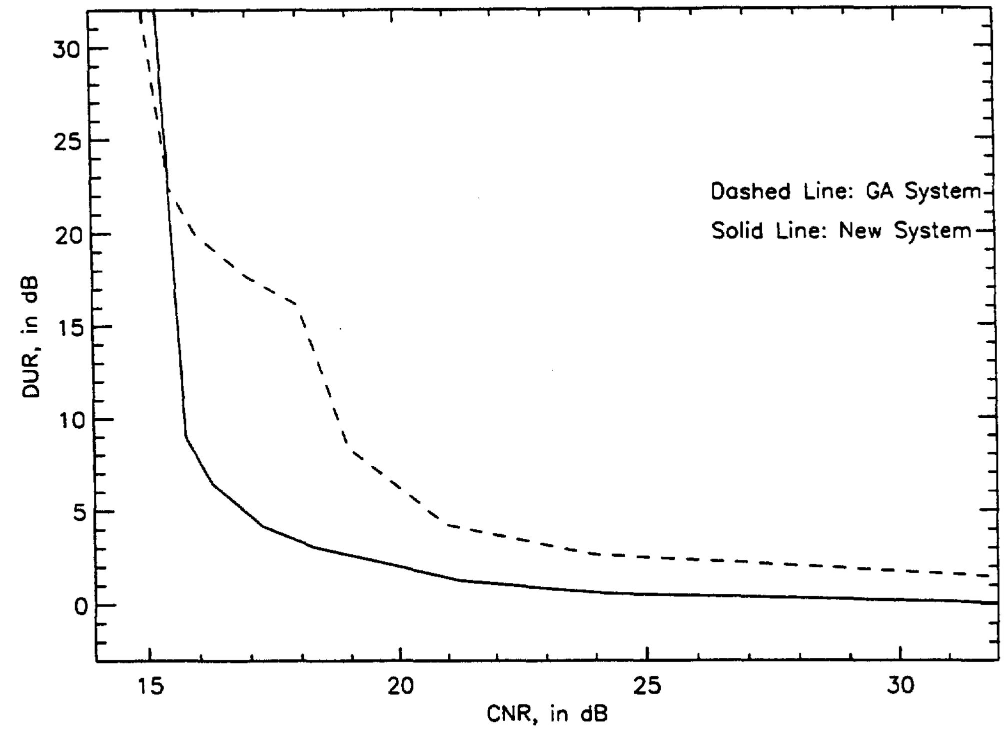


Figure 13. Performance of the New System and GA system with Text-over-Tulips Co-Channel Interference.

5.1.2 White-Noise-Only

We also measured the white-noise-only performance (at TOV) of the GA system and the new system. For the new system, we took data with the rejection filter enabled and bypassed. These results are shown in Table 3. The first two lines of Table 3 show the 0.3 dB better white-noise-only performance of the new system over the GA system when the rejection filter is bypassed.

	C/N @ TOV for White Noise Only (dB)
GA System	14.95
New System with Rejection Filter Bypassed	14.65
New System with Rejection Filter Enabled	15.29

TABLE 3. Measured (1/95) White-Noise-Only Performance for the New System and the GA System.

5.1.3 "Spectral Bump"

The new system demonstrated a 2 dB "bump" in the transmitted spectrum at a frequency at which the picture carrier would be located for an NTSC transmission on the same channel. This is because the precoder shapes the transmitted signal to be the inverse of the rejection filter shape, to a limited extent; this effect is minimized by the Mod-12 element of the precoder. Concerns were expressed by GA and ACATS members that this bump could cause NTSC viewers to perceive co-channel ATV interference from the new system to be more objectionable than that of the GA system (which has a "flat" transmitted spectrum) for the same transmitted ATV power. However, the fact that there is a spectral bump does not prove that this phenomenon is detrimental to co-channel NTSC reception. It is necessary to assess the impact, if any, by viewing NTSC pictures subject to interference from a new system ATV signal.

The effect of the "spectral bump" on co-channel NTSC was assessed by subjective testing, which included two expert observers, at Zenith. The testing used a bank of 9 typical receivers from various manufacturers. The two expert observers stated at that time that the ATV-into-NTSC interference caused by the new system was not more annoying than that caused by the GA system. Approximately 1/2 of a group of 10 observers noticed a difference between the character of the ATV-into-NTSC interference caused by the new system and the GA system, on 2 of the 9 receivers, in the case of ATV interference at CCIR Grade 3 into a flat gray field. For typical video and test patterns (like color bars), no observers (including the experts) noticed any difference. Even for the flat gray field, it was not clear to the observers who noticed a difference that the character of the noise (although somewhat different) was any more annoying for the new system. Some non-expert observers were not able to discern any difference between the interference caused by the new system and the GA system, even on the flat gray field. The expert observers adjusted the background lighting and video levels to approximate normal conditions to the extent possible within the laboratory. They also attempted to accentuate the difference between the GA system and the new system but were still unable to discern any difference for typical video and various test patterns.

5.1.4 Peak-to-Average Ratio

The peak-to-average power ratio was measured as 6.4 dB for the GA system, and 6.7 dB for the new system. To determine whether this 0.3 dB higher peak-to-average ratio for the new system would have any effect on the adjacent channel, and taboo ATV-into-NTSC performance of the system, it would be necessary to do subjective testing involving viewing NTSC images impaired by ATV interference from the new system. This would be done in a similar manner to what was done to assess the effect of the "spectral bump", as described in the preceding section. For the case of co-channel ATV-into-NTSC performance, the limited subjective testing at Zenith inherently included the effects of peak-to-average ratio, and it appeared that the new system performance was not negatively impacted.

The slightly higher peak-to-average ratio for the new system may require a slightly higher back-off of the transmitter to achieve out-of-band "splatter" performance identical to the GA system.

5.1.5 Burst Noise

The length of a burst of noise that the new system could tolerate, as determined according to Advanced Television Test Center (ATTC) test procedures [7] at the time of the testing at Zenith, was found to be shorter than that of the GA system. Burst noise tolerance of the new system was measured as 115 µs, vs. 192 µs for the GA system. However, these burst noise results for the new system were inconclusive, because no attempt had been made to optimize the byte and symbol interleaver sizes against burst noise. Since it is not known what level of burst noise resistance is really needed for proper operation in the field, duplicating the performance of the GA system can be considered the safest approach.

It is possible to make the new system burst noise performance equal to that of the GA system by increasing the size of the byte interleaver (and de-interleaver) associated with the Reed-Solomon code. The description in Section 3.4 reflects this new interleaver size. The additional memory involved would amount to about 2.65 kB.

5.1.6 Effect of Frequency Offset

For both the new system and the GA system, it is desirable to offset the ATV signal slightly to minimize the effects of co-channel or adjacent channel interference. By this we mean that the ATV spectrum is shifted upward in frequency from its nominal position (i.e., nominal would be ATV spectrum perfectly centered in the 6 MHz channel). Since both the GA system and the new system use frequency domain co-channel filters, it is clear that both systems will be affected adversely by a change in frequency offset. Two cases are considered to describe the effect of frequency offset on both the GA system and the new system.

5.1.6.1 Fixed Frequency Offset

In general, the rejection filter for the new system can be designed optimally for a given frequency offset. The GA system, even though not adaptive, also has sufficiently deep notches to compensate for small frequency offsets (up to 50 kHz). There is an optimal frequency offset for both systems, which was 59.2 kHz for both the GA system and the new system. However, it was known at the time of the testing at Zenith that another offset might be selected to optimize different performance criteria, e.g., adjacent channel interference performance.

Subsequent to the testing at Zenith, the ATTC chief scientist determined that to minimize annoying subjective effects of the color beat from upper-adjacent channel ATV-into-NTSC interference, the ATV signal should be offset into the upper adjacent channel by approximately 22.7 kHz. A detailed discussion of the rationale for choosing this offset is given in [8].

The difference in performance between an optimal offset of 59.2 kHz and that of 22.7 kHz is minimal for the new system. However, it is possible to optimize both the performance of the new system in co-channel NTSC-into-ATV performance as well as in upper-adjacent ATV-into-NTSC performance. This can be done by selecting one of the following frequency offsets. Note that f_h represents the NTSC horizontal line frequency of 15.734 kHz in the following discussion. These frequency offsets are chosen based on the following observations from [8]:

(1) the offset of 95.5 f_h totally removed the color beat from upper-adjacent channel ATV-into-NTSC interference, and,

(2) at the offset of 94 f_h the color stripes were vertical and present continuously.

Since the best offset for performance of the new system in co-channel NTSC-into-ATV would be an offset closest to 59.2 kHz, we suggest that the following offsets are also likely to alleviate the color-beat phenomenon:

96.5 f_h - 29.97 Hz => offset of 38.4 kHz;

97.5 f_h - 29.97 Hz => offset of 54.2 kHz;

98.5 f_h - 29.97 Hz => offset of 69.9 kHz.

Given the proximity of 54.2 kHz to 59.2 kHz, the best preference would be for the offset of 97.5 f_h - 29.97 Hz. The loss in performance using a non-optimal (other than 59.2 kHz) offset is minimal, so the above is only a method to optimize the new system to take into account adjacent channel interference as well.

5.1.6.2 Relative Frequency Offset

A small number of NTSC stations are located such that a given ATV transmitter's coverage area can be affected by more than one co-channel NTSC station. In some cases, to minimize co-channel interference between these NTSC stations, the center frequencies of these systems are offset by 10 kHz [15]. Since the new system uses a precoder at the ATV transmitter, the precoder will be designed for the frequency offset corresponding to one of the possibly several interfering NTSC transmitters. But that implies that locations affected by co-channel NTSC stations other than the one for which the new system has been designed may be adversely affected. The new system should be tested for this mismatch scenario, where the rejection filter is not optimal for the particular frequency offset of an interferer.

Note that the worst-case relative frequency offset is only 10 kHz (this is because, among all co-channel NTSC stations affecting a particular ATV coverage area, the rejection filter can be designed for the one which has at most 10 kHz offset with other NTSC stations). The new system will be affected minimally by this frequency offset. Zenith released some results which showed that the D/U ratio with co-channel-only for 10 kHz relative frequency offset from 59.2 kHz was higher by 0.6 dB. This is minimal considering that the coverage results are dominated by the entire co-channel-plus-noise curve and not by the D/U ratio presented by the co-channel-only results. Furthermore, it is possible to design the rejection filter to be somewhat wider for this scenario, and decrease even this performance loss. However, it should be noted that very few cases will exist in which multiple NTSC stations affect a given ATV coverage area, and so it is probably not necessary to optimize the rejection filter to account for these few cases.

5.2 Simulation Results

5.2.1 White Noise Performance

Simulation results for the new system under white noise with the rejection filter bypassed and enabled are shown in Fig. 14. The measured result for white noise performance (Table 3) of the new system with the rejection filter enabled was actually slightly better than the simulation results of Fig. 14. Four additional measurements were taken, and these all fell within 0.13 dB of those of Table 3, so the difference is not easily explained as measurement error. However, the simulation results of Fig. 14 do not include the effect of the symbol and byte interleavers. Since the white noise becomes colored after passing through the co-channel filter, the probable explanation for the difference is that the interleavers act to "re-randomize" the colored noise, giving a better real (measured) result.

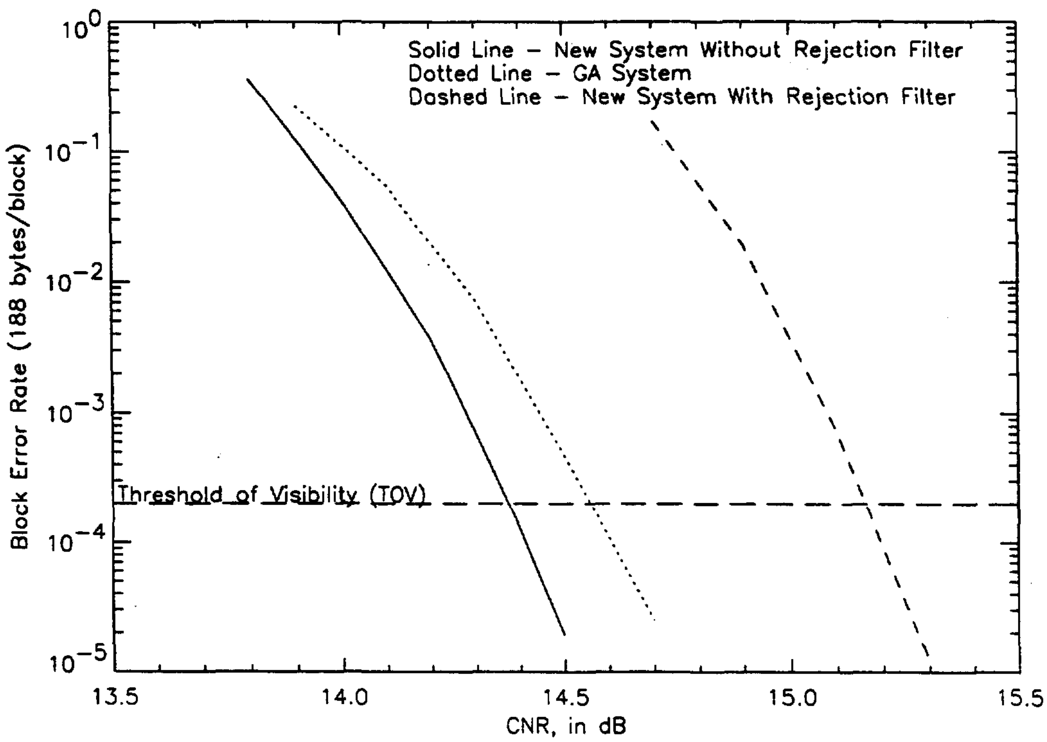


Figure 14. White Noise Performance Simulation Results for the New System With Its Rejection Filter Enabled and Bypassed. Performance of GA System With Its Comb Filter Switched Out Shown for Comparison.

5.2.2 Coverage Analysis

Results of our simulations of the effects of co-channel-plus-noise on ATV for the new system were forwarded to MSTV for coverage analysis in October of 1994. MSTV reported that the new system showed a 41% reduction in ATV population lost to NTSC interference with respect to the GA system.

The potential gains in service reported by MSTV in October, 1994 using simulation results for the new system were confirmed in January, 1995 using co-channel-plus-noise results measured on the new system and the GA system hardware for 3 different interfering NTSC video sequences as input to the MSTV coverage analysis software. MSTV's results for these cases, reproduced in Table 4, show that the reductions in ATV population lost to NTSC interference would range from 38% to 42% for the new system under the effect of interference from these video sequences. In Table 4, note that the total ATV population is an accepted measure which uses viewers times channels, not the total population of the U.S.

Comparing the results in columns four and five of Table 4 shows that it is necessary to compare systems using co-channel-plus-noise results, not just co-channel-only results. For example, the percentage improvement in ATV population lost to NTSC is actually lowest (by a small margin) for the Text-over-Tulips video, even though the improvement in co-channel-only is highest. Nonetheless, for all three video sequences the percentage improvement in ATV population lost to NTSC is much the same. This is because the difference in overall ATV service area is determined on a gross level by the area between the co-channel-plus noise curves of the two systems (Fig. 13), and this area is much the same for all interfering video sequences tested. The area between the co-channel-plus-noise curves for the new system and the GA system, for any choice of interfering video, is very much the same due to the 3 dB C/N threshold degradation caused when the GA system comb filter switches in.

Interfering NTSC Video Sequence	**Total ATV Population (millions)**	**GA System - ATV Pop. Lost to NTSC Interference (millions)**	**New System - ATV Pop. Lost to NTSC Interference (millions)**	**Reduction in ATV Pop. Lost to NTSC for New System (%)**	**Improvement in Co-Channel-Only Result for New System (dB)**
Text-over-Tulips	2912.03	150.57	93.03	38	1.38
Flower Garden	2912.03	140.45	81.20	42	1.00
Popple	2912.03	138.88	81.95	41	0.14

TABLE 4. Coverage Analysis Results for NTSC-into-ATV Based on Measured Data (1/95) for the New System and the GA System.

In applying the MSTV coverage analysis program to compare different transmission systems, the normal procedure is to adjust the ATV power by the difference in system C/N thresholds, to achieve equal ATV coverage for the systems. For the data of Table 4, the C/N threshold for the new system was assumed to be about 0.3 dB worse than for the GA system. It was also assumed that the new system rejection filter would be enabled at all ATV receivers (a possibly pessimistic assumption.) So the ATV power for the new system was increased by 0.3 dB (for all ATV transmitters nationwide) to obtain the coverage analysis results shown in Table 4 and the third column of Table 5.

	GA System	New System - transmit power increased over GA System	New System -same transmit power as GA System
Total ATV Population (millions)	2,912	2,912	2,900
ATV Population Lost to NTSC interference (millions)	151	93	94
NTSC Population Lost to ATV interference (millions)	109	113	109

TABLE 5. Coverage Analysis Results for New System Transmit Power Increased over GA System and for Equal Transmit Power for the New System and the GA system for Text-over-Tulips Video.

This power difference leads to a coverage analysis result of a larger number of NTSC viewers lost to ATV interference for the new system. According to the mathematics embodied in the coverage analysis, NTSC population lost to ATV interference would increase by about 3.3% (3.6 million population) for the new system. However, it is unlikely that an increase of 0.3 dB in ATV power can actually be observed by any NTSC viewer as causing any additional degradation. It is as if the noise on an NTSC set is increased by 0.3 dB. In any case, this loss of NTSC viewers to added ATV interference can be made zero by holding the ATV transmit power equal to that used for the GA system.

For the new system, holding the transmit power equal to the GA system will increase the ATV population lost to NTSC by approximately 1.0 million (with respect to ATV population lost by increasing the new system power by 0.3 dB), i.e., the reduction in ATV population lost to NTSC interference is still about 38% (for the Text-over-Tulips video sequence), with no loss in NTSC viewers. The results obtained by MSTV for equal transmit power between the new system and the GA system are shown in the fourth column of Table 5.

MSTV's results (Table 5) showed that the new system gains about 58 million ATV population, in total for all U.S. ATV stations, if the new system ATV power is increased by 0.3 dB with respect to the GA system. If the new system ATV power is made equal to the GA system power, to equalize the (mathematical) loss of NTSC population for both systems, then the new system still gains 57 million more ATV population.

5.2.3 Equalization Performance

New system equalization performance (using a decision-feedback equalizer) has been simulated and found to be essentially the same as that of the GA system. Performance was simulated with several test channels that were also used during testing of the GA hardware at ATTC [7],[8]. The results, given in Table 6, show that for the "strongest static echo" the new system equalizer lost about 0.3 dB in output SNR with respect to the GA system equalizer, whereas for more typical ensembles of ghosts the new system equalizer lost less than 0.1 dB. These losses are very small and for all practical purposes the new system and GA system equalizers perform the same.

	Equalizer Input S/N Ratio (dB)	Equalizer Output S/N Ratio (dB)
New System - Ensemble A	19.97	17.62
GA System -Ensemble A	20.04	17.70
New System - Ensemble C	20.04	17.62
GA System - Ensemble C	20.04	17.71
New System - Ensemble D	20.04	17.71
GA System - Ensemble D	20.03	17.75
New System - Largest Static Echo	29.99	26.65
GA System - Largest Static Echo	30.05	26.98

TABLE 6. Equalizer Performance for Various Ensembles of Multipath Components (as defined in [7]) for the New System and the GA system

Simulation results have confirmed that the Precoder Reset symbols have no adverse effect on equalizer performance. New system equalization performance equivalent to that of the GA system is ensured through producing a deterministic sequence by interrupting the precoder operation during the field sync segment.

5.2.4 Rejection Filter Mode Detection Performance

Two cases must be considered. First, consider the case when precoding is used at the transmitter. Then the robustness of the rejection filter (in/out) mode detection is very comparable to the robustness of the determination of the (8/16-) VSB mode [4] (which also effectively uses only eight symbols). Theoretically, the filter mode can be determined accurately at 0 dB CNR.

Now consider the case when precoding is not used at the transmitter. For this case it has been determined by simulations that the Filter Mode symbols are only mildly affected by the "additional multipath" (channel distortion) due to the presence of the rejection filter. The filter mode detection algorithm in this case suffers only by 0.5 dB as compared to the above case, i.e., the Filter Mode can be determined accurately at 0.5 dB CNR.

The above analysis assumes that the field sync can be accurately detected. By calculating the correlation for the various cases, we have determined that the worst-case performance degradation in the robustness of field-sync detection is less than 0.35 dB. For the GA system, field sync can be detected at a CNR lower than -5 dB (the field sync correlation is over 511 PN symbols) if the timing recovery operates, and it is this robustness which is affected by 0.35 dB. Thus field-sync detection performance is not degraded for the new system.

Given the above calculations, we do not foresee any problems with multipath, impulse noise, etc., in determining the Filter Mode. The rejection filter mode detection algorithm has essentially the same reliability as the VSB mode selection of the GA system.